 AR 10/587,345

PATENT SPECIFICATION 903,945

DRAWINGS ATTACHED.

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Date of filing Complete Specification: Oct. 23, 1958.

Application Date: Oct. 29, 1957. No. 33794/57.

Complete Specification Published: Aug. 22, 1962.

Index at Acceptance:—**Classes 110(3)**, B2V3B1, G10E(1BX:2A:2B); **and 122(4)**, Z12.

International Classification:—F02c. F01j.

COMPLETE SPECIFICATION.

Improvements in or relating to Gas-Turbine Engines.

We, ROLLS-ROYCE LIMITED, a British Company, of Nightingale Road, Derby, in the County of Derby, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention comprises improvements in or relating to gas-turbine engines of the kind which comprises a turbine rotor and a coaxial driven member, such as a compressor rotor, or the reduction gear of a propeller or both, connected to the turbine rotor by a driving shaft. Such an engine will be designated " a gas-turbine engine of the kind referred to ".

The invention is more particularly, though not exclusively, applicable to propeller-driving engines, or to " two-shaft " engines i.e. engines having a low-pressure compressor and a high-pressure compressor in series flow supplying air to combustion equipment, the combustion products from which are passed to a high-pressure turbine and a low-driving turbine in flow series, the low-pressure turbine driving the low-pressor compressor through a first shaft and the high-pressure turbine driving the high-pressure compressor through a second shaft.

It will be appreciated that, in the event of failure of the shaft driving the propeller or, in the case of a two-shaft engine, the shaft driving one of the compressors and propeller, the turbine from which the load has been removed, will accelerate rapidly and that, unless such acceleration is prevented, over-speeding and serious damage, such as bursting of the turbine rotor, may occur.

This invention has for an object to provide control means which responds rapidly to shaft failure to prevent such over-speeding.

According to the present invention, in a gas-turbine engine of the kind referred to, there is provided means connected with the rotor assembly of the engine adjacent the ends of the driving shaft so as to rotate therewith, said means including a part which is caused to be displaced axially by the relative rotation of the ends of the driving shaft on failure thereof, a pressure-fluid-containing member, such as a capsule, which is fractured on such axial displacement and pressure-responsive means operated by fall of pressure within the pressure-fluid containing member and operative to cut-off or reduce the fuel supply to the engine.

According to a feature of this invention, the means may comprise a rod or spindle which extends through the driving shaft and has a driving, e.g. splined, connection with the rotor assembly at one end and has at the other end of the rotor assembly a splined connection with a sleeve which in turn has a threaded connection with the rotor assembly, so that on failure of the driving shaft the sleeve is rotated relative to the portion of the rotor assembly with which it has the threaded connection and is displaced axially of the rotor assembly. The pressure-fluid-containing capsule or like member is preferably supported in stationary structure in axial alignment with the sleeve so that on such axial displacement the capsule or like member is struck and thereby fractured to permit the pressure fluid to escape.

In one arrangement of this invention the pressure-responsive means is a bellows de-

vice connected with the capsule or like member so as normally to be subjected to the same pressure as exists in the capsule or like member, and connected also to a shut-off cock in the fuel system so that on fracture of the capsule or like member the bellows changes in length and causes the shut-off cock to close. The bellows may either operate directly on the shut-off cock or may operate a catch to release the shut-off cock for closure under the influence of a spring. The latter arrangement has the advantage that the catch can be released by a smaller change in length of the bellows than would normally be required for direct closing of the cock.

In another arrangement of this invention, the pressure-responsive means, such as a bellows or flexible diaphragm, actuates a bleed valve for controlling the servo-pressure operating in a servo-mechanism which controls a fuel pump in the engine fuel system, so that when the capsule or like member is fractured the bleed valve is operated in a manner to cause rapid reduction of the fuel delivery of the pump.

The invention is illustrated in the accompanying drawings in which:—

Figure 1 shows a gas-turbine engine provided with a failure control of this invention;

Figure 2 shows a modification of Figure 1; and

Figure 3 shows another modification.

The engine shown in Figure 1 is a "two-shaft" gas-turbine engine, but it will be understood that the invention may be employed with any form of gas turbine.

The engine comprises a low-pressure compressor 10, a high-pressure compressor 11, combustion equipment 12, a high-pressure turbine 13 and a low-pressure turbine 14 in flow series. The rotor 11*a* of the high-pressure compressor 11 is driven through a hollow shaft 15 by the high-pressure turbine rotor 13*a*, and the low-pressure turbine rotor 14*a* drives the low-pressure compressor rotor 10*a* through a shaft 16 which is hollow and extends coaxially within the shaft 15. The low-pressure turbine shaft 16 also drives by means of a shaft 16*a* a high-speed pinion 17 of a reduction gear (not shown) for an airscrew driven by the engine. The exhaust gas from the turbine 14 flows into an exhaust unit 31.

The combustion equipment 12 is fed with fuel to be burnt with air compressed in the compressors 10, 11. The fuel is drawn from a tank 18 by a pump 19 and is delivered by the pump to a supply control deivce 20 from which the fuel flows through supply lines 21, 22 to fuel manifolds 23, 24 feeding the fuel ejectors 25.

In order to prevent undesirable overspeeding of the low-pressure turbine rotor 14*a* in the event that shaft 16 or shaft 16*a* fails in operation, there is provided means whereby the fuel supply to the injectors 25 is cut-off on failure of either of the shafts.

The illustrated means for this purpose comprises a rod or spindle 26 which extends co-axially through the low-pressure rotor assembly 16*a*, 10*a*, 16, 14*a*, and has at the high-speed pinion end of the assembly a splined connection 27 with the assembly and has at the turbine end of the assembly a splined connection 28 with a sleeve 29 which is formed externally with a quick-thread 30 engaging a threaded bore in the turbine rotor 14*a*. In the event of failure of either the shaft 16 or shaft 16*a*, the turbine rotor 14*a* will tend to over-run the high-speed pinion 17 and the sleeve 29 by reason of the driving connection which is maintained between the sleeve 29 and the high speed pinion 17 by the splines 28, rod 26 and splines 27. Thus due to the quick thread 30 the sleeve 29 will be moved axially and the hand of the thread 30 is selected so that the sleeve is moved rearwards towards the exhaust unit 31 of the engine.

A capsule 32 is mounted within the exhaust unit 31 in axial alignment with the sleeve 29 and the capsule 32 is connected by a tube 33 to the interior of a bellows device 34 which forms part of a shut-off cock 35 connected in the fuel delivery pipes 21, 22. The capsule 32, tube 33 and bellows 34 are filled with liquid under pressure, the liquid preferably being of low coefficient of thermal expansion.

The bellows 34 acts on one end of a valve member 35*a* slidable in a valve body 35*b* and a compression spring 36 bears on the opposite end of the valve member 35*a*. The bellows 34 and spring 36 are accommodated in the body 35*b* in chambers 37, 38 respectively.

Each of the fuel delivery pipes 21, 22 has portions upstream and downstream of the shut-off cock 35 and normally these portions are interconnected by annular recesses 40, 41 in the valve member 35*a*.

The valve body 35*b* also has connected to it drain pipes 42 which are normally covered by the lands of the valve member 35*a*.

The chamber 37 is connected by pipe 37*a* to one drain pipe 42 and the chamber 38 is connected to the other drain pipe 42 by a pipe 38*a* to nullify the pumping effect of movement of valve member 35*a*.

In the event of failure of either the shaft 16 or shaft 16*a*, the sleeve 29 is displaced rearwardly, and strikes and fractures the capsule 32 so that the pressure liquid escapes from it and from the tube 33 and bellows 34. The bellows 34 therefore collapses and the valve member 35*a* is moved to the

right by the spring 36 until a flange 35*c* on the valve member 35*a* abuts a shoulder 35*d* on the valve body 35*b* when the downstream portions of the fuel pipes 21, 22 are cut-off from their upstream portions and are placed in communication with drain pipes 42. The supply of fuel to the engine is thus cut-off and over-speeding is avoided.

In a modification (Figure 2), the spring 36 is replaced by a bellows device 43 which is filled with a gas under pressure, the bellows 34, pipe 33 and capsule 32 also being filled with the same gas under the same pressure. The chambers 37 and 38 are interconnected by a duct 39 running through the valve member 35*a*. On fracture of the capsule 32, the bellows 43 acts in the same way as the spring 36, but with this arrangement, if the bellows 43 is filled with the same fluid as the capsule 32, tube 33 and bellows 34, a temperature compensating effect is obtained.

In the arrangement shown in Figure 2 a further compensating pipe and capsule could be connected to the bellows device 43, the further capsule being positioned adjacent capsule 32 but in a position where it would not be fractured on shaft failure.

Instead of arranging the bellows 34 to act directly on the valve member 35*a* as in Figure 1, a bellows may be arranged to release a catch holding the valve member 35*a* in its normal position. One such arrangement is shown in Figure 3, in which the bellows 134 is arranged in a chamber 137 with its axis at right angles to the line of movement of the valve member 35*a*. The bellows 134 carries a nib 135 which engages a recess 136 in the valve member 35*a*. On fracture of the capsule 32 and collapse of the bellows 134, the nib 135 is withdrawn from the recess 136 releasing the valve member 35*a* for movement under the action of spring 36 or bellows 43. This arrangement has the advantage that a quicker operation of the valve member 35*a* is obtained, since the valve member 35*a* is fully released from the action of the bellows 134 after a reduction in its length which is small as compared with the reduction in length of bellows 34 required for full operation of the valve member 35*a* and thus full operation of the valve member 35*a* and thus full operation of the valve member may be obtained before all the pressure fluid has escaped from the bellows.

The invention is also applicable in gas-turbine engines having a fuel system comprising a fuel pump whereof the rate of fuel delivery is controlled by means of a servo-mechanism. In one well-known form, the pump is a multi-plunger pump and the servo-mechanism comprises a piston connected with a swash plate device for varying the stroke of pump plungers, the piston working in a cylinder one end space of which is directly connected with the pump delivery and the other end space of which is connected with the pump delivery through a restrictor and has a bleed outlet. In such an arrangement the position of the piston in the cylinder of the servo-mechanism, and thus the delivery of the pump, is controlled by varying the rate of flow of servo fluid through the bleed outlet.

In applying the present invention to such a fuel system an auxiliary bleed outlet may be provided from the second end space of the cylinder of the servo-mechanism, which auxiliary outlet is controlled by a valve member normally held closed by a pressure-responsive device, such as the bellows 34 or a flexible diaphragm, which is loaded in the sense of closure by pressure fluid contained in the capsule 32. On fracture of the capsule, the fluid pressure load on the pressure-responsive device decreases and the valve controlling the auxiliary bleed outlet from the servo-mechanism opens rapidly increasing the bleed flow from the second end of the cylinder of the servo-mechanism and causing movement of the servo pistons in a direction to reduce the pump delivery.

Whilst the invention has been described above in connection with a compound type engine of the propeller-driving kind, it will be understood that the invention has useful application in connection with any form of gas-turbine engine in which a turbine is connected to drive a load through a shaft which is liable to fracture in operation.

WHAT WE CLAIM IS:—

1. A gas-turbine engine of the kind referred to, wherein there is provided means connected with the rotor assembly of the engine adjacent the ends of the driving shaft so as to rotate therewith, said means including a part which is caused to be displaced axially by the relative rotation of the ends of the driving shaft on failure thereof, a pressure-fluid-containing member which is fractured on such axial displacement and pressure-responsive means operated by fall of pressure within the pressure-fluid containing member and operative to cut-off or reduce the fuel supply to the engine.

2. A gas-turbine engine according to Claim 1, wherein the pressure-fluid containing means is a capsule or the like which is struck and fractured by the axially-displaceable part on occurrence of such axial displacement.

3. A gas-turbine engine according to Claim 1 or Claim 2, wherein the said means connected with the rotor assembly comprises a rod or spindle which extends through the driving shaft and has a driving, e.g. spline, connection with the rotor assembly at one end and has at the other end of the rotor

assembly a splined connection with a sleeve which in turn has a threaded connection with the rotor assembly, so that on failure of the driving shaft the sleeve is rotated relative to the portion of the rotor assembly with which it has the threaded connection and is displaced axially of the rotor assembly.

4. A gas-turbine engine according to Claim 1, Claim 2 or Claim 3 wherein the pressure-responsive means is a bellows device connected with the pressure-fluid-containing member so as normally to be subjecte d to the same pressure as exists in the pressure-fluid-containing member, and connected also to a shut-off cock in the fuel system so that on fracture of the pressure-fluid-containing member the bellows changes in length and causes the shut-off cock to close.

5. A gas-turbine engine according to Claim 4, wherein the bellows operates directly on the shut-off cock, the shut-off cock including a movable valve element which is displaced in accordance with change of length of the bellows.

6. A gas-turbine engine according to Claim 5, comprising a spring loading the movable valve element in the sense of movement occurring on change of length of the bellows.

7. A gas-turbine engine according to Claim 4, wherein the bellows by its change of length operates a catch to release the shut-off cock for closure under the influence of a spring.

8. A gas-turbine engine according to Claim 6 or Claim 7, having a further bellows device in place of the spring, the further bellows being subjected to a gas under pressure such that, on change of length of the bellows connected to the capsule or like member, the further bellows also changes in length and operates the valve, the fluid in the capsule and like member and its associated bellows also being said gas.

9. A gas-turbine engine according to Claim 8, wherein the further bellows has connected with it a capsule which is positioned adjacent to the fracturable capsule or like member but out of the path of the axially displaceable part.

10. A gas-turbine engine according to any of Claims 6 to 9 wherein the shut-off cock has a movable piston valve element slidable in a valve body, the spring or the further bellows being in a chamber at one end of the body and the bellows associated with the fracturable capsule or the like being in a chamber at the other end of the body, the chambers being interconnected and also having outlets to drain.

11. A gas-turbine engine according to any of Claims 1 to 3, wherein the pressure responsive means operates a valve controlling the operation of a servo-mechanism for actuating a fuel pump delivering fuel to the engine, such that on fracture of the pressure-fluid-containing member the pump delivery is rapidly reduced.

12. A gas-turbine engine of the kind referred to when comprising a shaft failure control substantially as hereinbefore described with reference to and as illustrated in Figure 1 of the drawings.

13. A gas-turbine engine according to Claim 12 modified substantially as hereinbefore described with reference to and as illustrated in Figure 2 of the drawings.

14. A gas-turbine engine according to Claim 12 or Claim 13 modified substantially as hereinbefore described with reference to and as illustrated in Figure 3 of the drawings.

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Reference has been directed in pursuance of Section 9, subsection (1) of the Patents Act, 1949, to Patent No. 843,479.

PROVISIONAL SPECIFICATION.

Improvements in or relating to Gas-Turbine Engines.

We, ROLLS-ROYCE LIMITED, a British Company, of Nightingale Road, Derby, in the County of Derby, do hereby declare this invention to be described in the following statement:—

This invention comprises improvements in or relating to gas-turbine engines of the kind which comprises a turbine rotor and a co-axial driven member, such as a compressor rotor, or the reduction gear of a propellor or both, which are interconnected by a driving shaft.

The invention is more particularly, though not exclusively, applicable to propeller-driving engines or to "two-shaft" engines i.e. engines having a low-pressure compressor and a high-pressure compressor in series flow supplying air to combustion equipment, the combustion products from which are passed to a high-pressure turbine and a low-pressure turbine in flow series, the low-pressure turbine driving the low-pressure compressor through a first shaft and the high-pressure turbine driving the high-pressure compressor through a second shaft.

It will be appreciated that, in the event

of failure of the shaft driving the propellor or, in the case of a two-shaft engine, the shaft driving one of the compressors, the turbine will accelerate rapidly due to the removal of the load it is driving and that, unless such acceleration is prevented, over-speeding and serious damage, such as bursting of the turbine rotor, may occur.

This invention has for an object to provide control means which responds rapidly to shaft failure to prevent such over-speeding.

According to the present invention, in a gas-turbine engine of the kind referred to, there is provided means connected with the rotor assembly of the engine adjacent the ends of the driving shaft so as to rotate therewith, said means including a part which due to the relative rotation of the ends of the driving shaft on failure thereof is caused to be displaced axially, a pressure-fluid-containing member, such as a capsule, which is fractured on such axial displacement and pressure-responsive means operated by fall of pressure within the member and operative to cut-off or reduce the fuel supply to the engine.

According to a feature of this invention, the means may comprise a rod or spindle which extends through the driving shaft and has a driving, e.g. splined, connection with the rotor assembly at one end and has at the other end of the rotor assembly a splined connection with a sleeve which in turn has a threaded connection with the rotor assembly, so that on failure of the driving shaft the sleeve is rotated relative to the portion of the rotor assembly with which it has the threaded connection and is displaced axially of the rotor assembly. The pressure-fluid-containing capsule or like member is preferably supported in stationary structure in axial alignment with the sleeve so that on such axial displacement the capsule or like member is fractured to permit the pressure fluid to escape.

In one arrangement of this invention the pressure-responsive means is a bellows device connected with the capsule or like member so as normally to be subjected to the same pressure as exists in the capsule or like member, and connected also to a shut-off cock in the fuel system so that on fracture of the capsule or like member the bellows changes in length and causes the shut-off cock to close. The bellows may either operate directly on the shut-off cock or may operate a catch for releasing the shut-off cock for closure under the influence of a spring. The latter arrangement has the advantage that the catch can be released by a smaller change in length of the bellows than would normally be required for direct closing of the cock.

In another arrangement of this invention, the pressure-responsive means, such as a bellows or flexible diaphragm, actuates a bleed valve for controlling the servo-pressure operating in a servo-mechanism which controls a fuel pump in the engine fuel system, so that when the capsule or like member is fractured the bleed valve is operated in a manner to cause rapid reduction of the fuel delivery of the pump.

The invention is illustrated in the accompanying drawings in which:—

Figure 1 shows a gas-turbine engine provided with a failure control of this invention;

Figure 2 shows a modification of Figure 1; and

Figure 3 shows another modification.

The engine shown in Figure 1 is a compound gas-turbine engine, but it will be understood that the invention may be employed with any form of gas turbine.

The engine comprises a low-pressure compressor 10, a high-pressure compressor 11, combustion equipment 12, a high-pressure turbine 13 and a low-pressure turbine 14 in flow series. The rotor 11*a* of the high-pressure compressor 11 is driven through a hollow shaft 15 by the high-pressure turbine rotor 13*a*, and the low-pressure turbine rotor 14*a* drives low-pressure compressor rotor 10*a* through a shaft 16 which is hollow and extends coaxially within the shaft 15. The low-pressure turbine 16 also drives a high-speed pinion 17 of a reduction gear for an airscrew driven by the engine. The exhaust gas from the turbine 14 flows into an exhaust unit 31.

The combustion equipment 12 is fed with fuel to be burnt with air compressed in the compressors 10, 11. The fuel is drawn from a tank 18 by a pump 19 and is delivered by the pump to a supply control device 20 from which the fuel flows through supply lines 21, 22 to fuel manifolds 23, 24 feeding the fuel injectors 25.

In order to prevent undesirable over-speedinfig of the low-pressure turbine rotor 14*a* in the event that shaft 16 fails in operation, there is provided means whereby the fuel supply to the injectors 25 is cut-off on failure of the shaft.

The illustrated means for this purpose comprises a rod or spindle 26 which extends coaxially through the low-pressure rotor assembly 10*a*, 16, 14*a*, has at the compressor end of the assembly a splined connection 27 with the assembly and has at the turbine end of the assembly a splined connection 28 with a sleeve 29 which is formed externally with a quick-thread 30 engaging a threaded bore in the turbine rotor 14*a*. In the event of failure of the shaft 16, the turbine rotor 14*a* will tend to over-run the compressor rotor 10*a* and also the sleeve 29, due to the driving connection which is maintained through splines 28, rod 26 and splines 27 between the sleeve 29 and the compressor

rotor $10a$. Thus due to the quick thread 30 the sleeve 29 will be moved axially and the hand of the thread 30 is selected so that the sleeve is moved rearwards towards the exhaust unit 31 of the engine.

A capsule 32 is mounted within the exhaust unit 31 in axial alignment with the sleeve 29 and the capsule 32 is connected by a tube 33 to the interior of a bellows device 34 which forms part of a shut-off cock 35 connected in the fuel delivery pipes 21, 22. The capsule 32, tube 33 and bellows 34 are filled with liquid under pressure, the liquid preferably being of low coefficient of thermal expansion.

The bellows 34 acts on one end of a valve member $35a$ slidable in a valve body $35b$ and a compression spring 36 bears on the opposite end of the valve member $35a$. The bellows 34 and spring 36 are accommodated in the body $35b$ in chambers 37, 38 respectively and the chambers are interconnected by a duct 39 running through the valve member $35a$.

Each of the fuel delivery pipes 21, 22 has portions upstream and downstream of the shut-off cock 35 and normally these portions are interconnected by annular recesses 40, 41 in the valve member $35a$.

The valve body $35b$ also has connected to it drain pipes 42 which are normally covered by the lands of the valve member $35a$.

The chamber 37 is connected by pipe $37a$ to the drain pipe 42 and the chamber 38 is connected to the drain pipe 42 by a pipe $38a$ to nullify the pumping effect of movement of valve member $35a$.

In the event of failure of the shaft 16, the sleeve 29 is displaced rearwardly to hit and fracture the capsule 32 so that the pressure liquid escapes from it and from the tube 33 and bellows 34. The bellows 34 therefore collapses and the valve member $35a$ is moved to the right by the spring 36 until a flange $35c$ on the valve member $35a$ abuts a shoulder $35d$ on the valve body $35b$ when the downstream portions of the fuel pipes 21, 22 are cut-off from their upstream portions and are placed in communication with drain pipes 42. The supply of fuel to the engine is thus cut-off and overspeeding is avoided.

In a modification (Figure 2), the spring 36 is replaced by a bellows device 43 which is filled with a gas under pressure, the bellows 34, pipe 33 and capsule 32 also being filled with the same gas under the same pressure. On fracture of the capsule 32, the bellows 43 acts in the same way as the spring 36, but with this arrangement, if the bellows 43 is filled with the same fluid as the capsule 32, tube 33 and bellows 34, a temperature-compensating effect is obtained.

In the arrangement shown in Figure 2 a further compensating pipe and capsule could be connected to the bellows device 43, the further capsule being positioned adjacent capsule 32 but in a position where it would not be fractured on shaft failure.

Instead of arranging the bellows 34 to act directly on the valve member $35a$ as in Figure 1, a bellows may be arranged to release a catch holding the valve member $35a$ in its normal position. One such arrangement is shown in Figure 3, in which the bellows 134 is arranged in a chamber 137 with its axis at right angles to the line of movement of the valve member $35a$. The bellows 134 carries a nib 135 which engages a recess 136 in the valve member $35a$. On fracture of the capsule 32 and collapse of the bellows 134, the nib 135 is withdrawn from the recess 136 releasing the valve member $35a$ for movement under the action of spring 36 or bellows 43. This arrangement has the advantage that a quicker operation of the valve member $35a$ is obtained, since the valve member $35a$ is fully released from the action of the bellows 134 after a reduction in its length which is small as compared with the reduction in length of bellows 34 required for full operation of the valve member $35a$ and thus full operation of the valve member may be obtained before all the pressure fluid has escaped from the bellows.

The invention is also applicable in gas-turbine engines having a fuel system comprising a fuel pump whereof the rate of fuel delivery is controlled by means of a servo-mechanism. In one well-known form, the pump is a multi-plunger pump and the servo-mechanism comprises a piston connected with a swash plate device for varying the stroke of pump plungers, the piston working in a cylinder one end space of which is directly connected with the pump delivery and the other end space of which is connected with the pump delivery through a restrictor and has a bleed outlet. In such an arrangement the position of the piston in the cylinder of the servo-mechanism, and thus the delivery of the pump, is controlled by varying the rate of flow of servo fluid through the bleed outlet.

In applying the present invention to such a fuel system an auxiliary bleed outlet may be provided from the second end space of the cylinder of the servo-mechanism, which auxiliary outlet is controlled by a valve member normally held closed by a pressure-responsive device, such as the bellows 34 or a flexible diaphragm, which is loaded in the sense of closure by pressure fluid contained in the capsule 32. On fracture of the capsule, the fluid pressure load on the pressure-responsive device decreases and the valve controlling the auxiliary bleed outlet from the servo-mechanism opens rapidly increas-

ing the bleed flow from the second end of the cylinder of the servo-mechanism and causing movement of the servo piston in a direction to reduce the pump delivery.

Whilst the invention has been described above in connection with a compound type engine of the propeller-driving kind, it will be understood that the invention has useful application in connection with any form of gas-turbine engine in which a turbine rotor is connected to drive a load through a shaft which is liable to fracture in operation.

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Abingdon : Printed for Her Majesty's Stationery Office, by Burgess & Son (Abingdon), Ltd.—1962.
Published at The Patent Office, 25, Southampton Buildings, London, W.C.2,
from which copies may be obtained.

903,945 COMPLETE SPECIFICATION
1 SHEET
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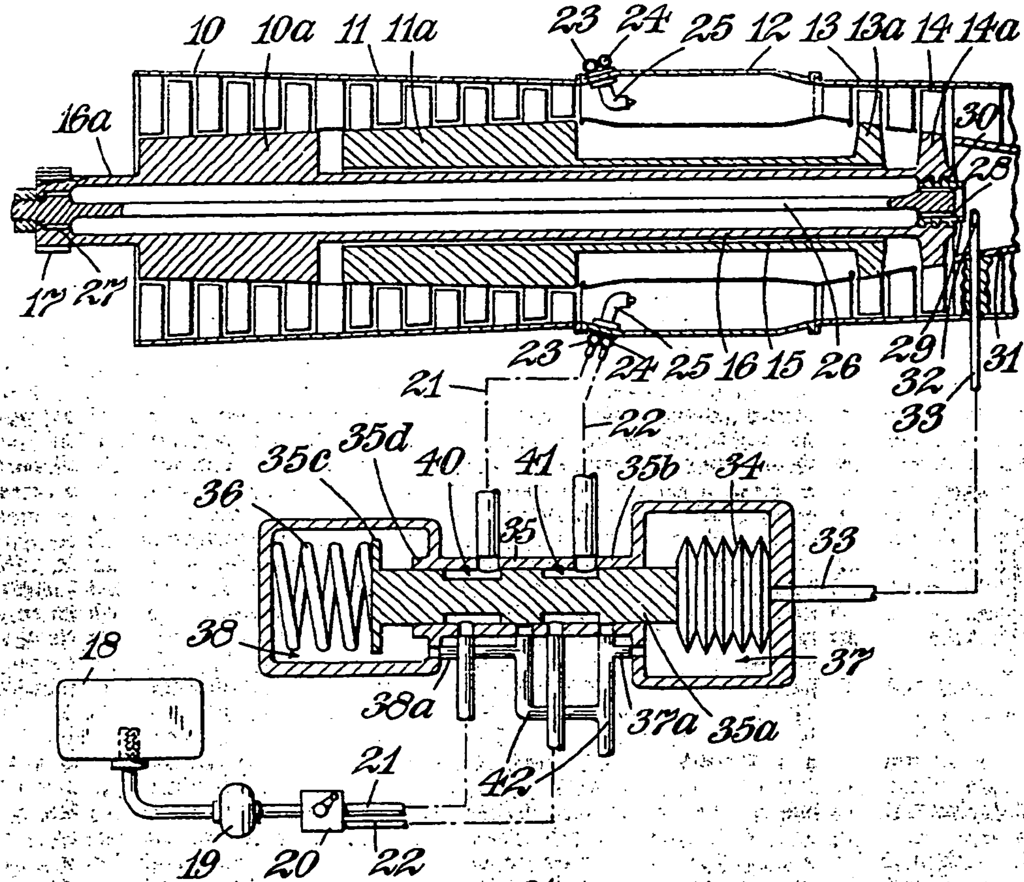
Fig.1.



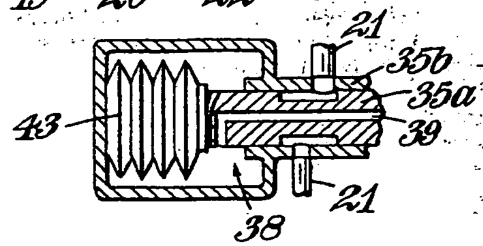
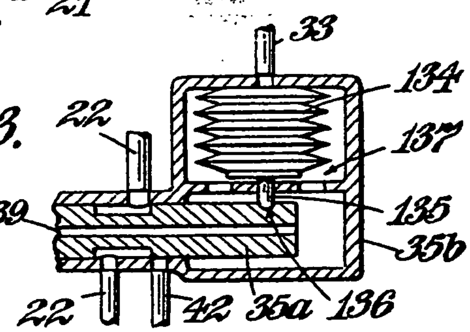


Fig.2.

Fig.3.



903,945 PROVISIONAL SPECIFICATION

1 SHEET

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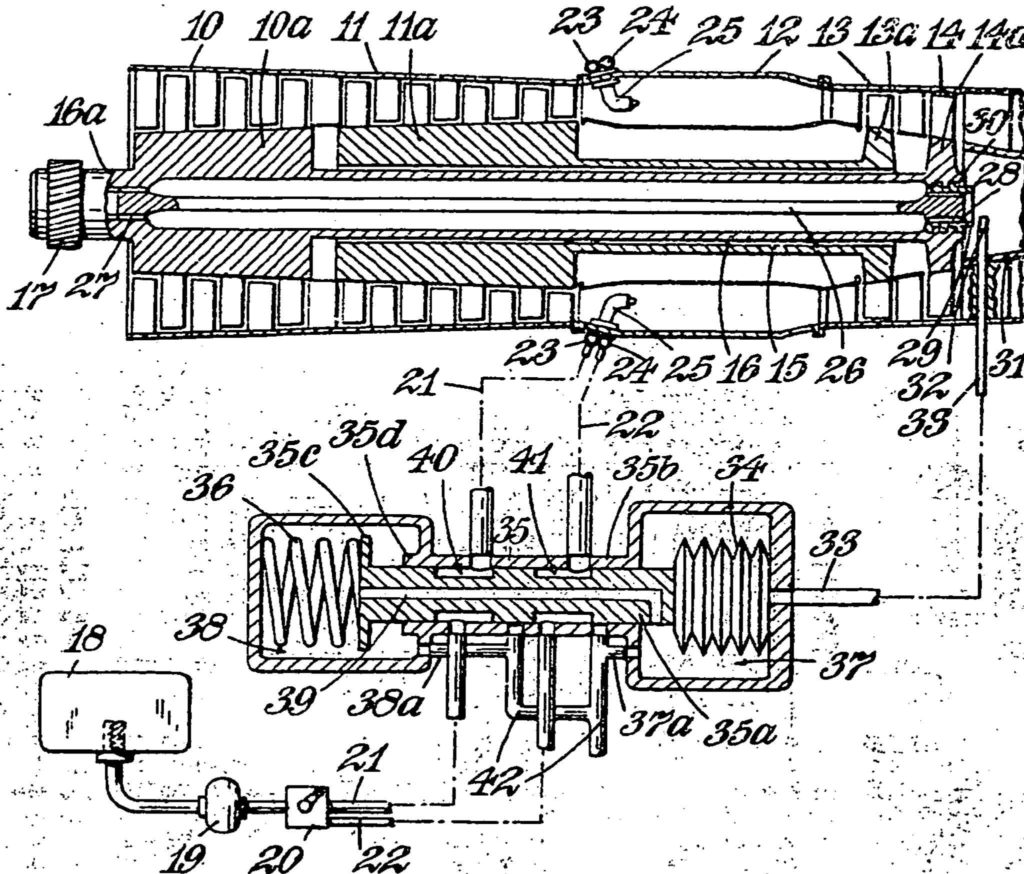
Fig.1.



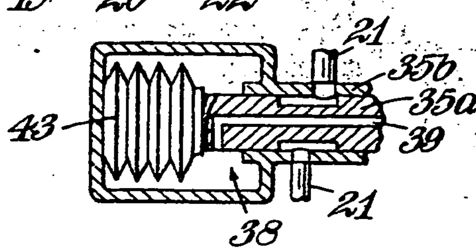


Fig.2.

Fig.3.